

APPENDIX P TO THE EARTH SYSTEMATIC MISSIONS PROGRAM PLAN
PROGRAM-LEVEL REQUIREMENTS ON THE ICESAT-2 PROJECT

The ICESat-2 Mission

Level-1 Requirements and Mission Success Criteria

Version 4.0
Date: 8 Jul 2013

Document Revision History

Revision	Date	Sections Changed
1.0	11 Dec 09	Baseline
2.0	22 Jul 11	<ol style="list-style-type: none"> 1. Modified to comply with new Earth Sciences Division (ESD) template; 2. Added explanation that “science” refers to research, applied research, and applications. 3. Updated narrative regarding Science Definition Team (SDT) and Science Team (ST); 4. Updated Section 4.5.2, Applied Science Data Requirements; 5. Deleted Sections 5.3 and 5.4, which were redundant with other sections and overriding NASA directives; 6. Baseline and threshold requirements relaxed to maintain costs within allocable budget; 7. Added requirement for dynamic ice features; 8. Added requirement that data be used in conjunction with ICESat for decadal time scale ice elevation changes; 9. Rewrote requirements for sea-ice freeboard and global vegetation height; 10. Added mission lifetime “goal” (not a requirement) to Baseline Science Objectives; 11. Combined “Full” and “Minimum” Mission Success Criteria sections into a single simpler section; 12. Total mission cost and LRD targets adjusted to reflect current baseline; 13. Added the following previously omitted requirements: Science Instrument, Ground System, and Applied Science Data; 14. Updated S-Band uplink from Ground Network (GN) to Near-Earth Network (NEN); 15. Updated signatories within Concurrences Section; 16. NASA Science Plan objectives supported by this mission added to Section 2.0; 17. Modified Figure 1 to be purely positions; 18. Added acceptable Launch Vehicle category to Section 4.3; 19. Added Preface explaining current TBRs.
3.0	17 Dec 12	<ol style="list-style-type: none"> 20. Deleted Preface; 21. Used separate bullets to describe NASA-KSC and NASA-SMD/ESD responsibilities in Section 3.1; 22. Updated Mission Success Criteria per new direction; 23. Updated cost and LRD to reflect new management commitment (excludes UFE and pre-Phase A costs);

		24. Updated personnel within Approvals and Concurrences.
4.0	8 Jul 2013	25. Updated TBD LV costs with actual LV costs in Section 5.1; 26. EPO descope and funding reduction from project (FY14 onward) in Section 8.0; 27. Updated personnel within Approvals and Concurrences.

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1.0 SCOPE

This appendix to the Earth Systematic Missions (ESM) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on the NASA-Goddard Space Flight Center (GSFC) for the development and operation of the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) Project of the ESM Program. Requirements begin in Section 4. Sections 1, 2 and 3 are intended to set the context for the requirements that follow.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase.

Program authority is delegated from the Associate Administrator (AA) for the Science Mission Directorate (SMD) through the Earth Science Division (ESD) within SMD to the ESM Program Manager at NASA-GSFC.

The NASA-GSFC is responsible for design, development, test, mission operations, and data verification tasks and will coordinate the work of all contractors and co-investigators.

Changes to information and requirements contained in this document require approval by the SMD, NASA Headquarters, and by the officials that approved the original.

2.0 SCIENCE DEFINITION

ICESat-2 supports the *2011 NASA Strategic Plan* objective of NASA's Earth Science efforts in "Strategic Goal 2: Expand scientific understanding of the Earth and the universe in which we live," and specifically in "Sub-goal 2.1: Advance Earth system science to meet the challenges of climate and environmental change." To fulfill this strategic goal, the *2010 Science Plan For NASA's Science Mission Directorate* states that "From space, researchers view the Earth as a planet and study it as a complex, interacting dynamic system with diverse components: the oceans, atmosphere, continents, ice sheets, and life itself. NASA's Earth Science Program observes and tracks global-scale changes, connecting causes to effects, and studies regional changes in their global context and understands global change and uses Earth observations and scientific understanding in service to society." ICESat-2 further contributes to the Earth Science Mission Directorate's goal of "Progress in understanding the role of oceans, atmosphere, and ice in the climate system and in improving predictive capability for its future evolution." ICESat-2, as part of the Earth Systematic Missions Program is contributing to the goal of "developing a scientific understanding of the Earth systems and its response to natural and human-induced forces."

"Science" implies research, applied research, and applications for the purposes of this requirements document.

2.1 Baseline Science Objectives

The ICESat-2 Project will implement a space-borne mission designed to collect altimetric measurements of the Earth's surface, optimized to measure the heights and freeboard of polar ice. ICESat-2 measurements will yield a critical data set that will enable science and applications users to:

- 1) Quantify polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions;
- 2) Quantify regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice sheet models; this includes quantifying the regional evolution of ice sheet change, such as how changes at outlet glacier termini propagate inward.
- 3) Estimate sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture;
- 4) Measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change.

ICESat-2 measurements will span a minimum of three years with a five-year goal.

2.2 Science Instrument Summary Description

The ICESat-2 observatory employs a dedicated spacecraft with an instrument that will be launched into a near-polar orbit on an expendable Launch Vehicle (LV). ICESat-2 will have a laser altimeter and other necessary instrumentation to produce calibrated and validated ice surface elevations. ICESat-2 will measure surface slopes to enable unambiguous separation of slopes and elevation changes. ICESat-2 will make measurements for a 3-year period which, when combined with ICESat-1 data, produce elevation differences that span a 15-year period. ICESat-2 will determine ice sheet elevation, its temporal change and determine the elevation variations over spatial scales that range from outlet glaciers (100 km²) to ice sheets (>1.5 million km²) at latitudes up to at least 86°. ICESat-2 will measure sea ice freeboard to enable ice thickness estimates, and it will measure vegetation canopy height in order to enable biomass estimation.

3.0 PROJECT DEFINITION

3.1 Project Organization and Management

The ICESat-2 Project Manager will report to NASA according to Figure 1.

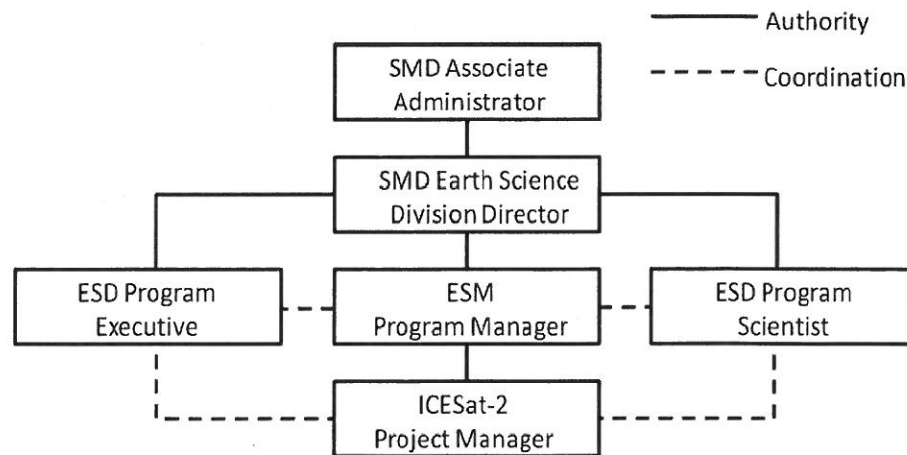


Figure 1. ICESat-2 Lines of Authority and Coordination

The ICESat-2 Project Manager has overall management responsibility for the success of the project. The ICESat-2 Project Scientist has overall management responsibility for the science elements of the project. Specific assigned roles and responsibilities are:

- NASA-GSFC is responsible for providing: the Project Scientist; project management; system engineering and mission design; safety and mission assurance; the Light Detection and Ranging (LIDAR) system; spacecraft; instrument integration; launch; mission operations and the associated mission operations ground data system; science data processing and delivery of calibrated/validated science data products to an archive for public distribution.
- NASA-Kennedy Space Center (KSC) is responsible for providing an LV and launch services for ICESat-2.
- NASA-SMD/ESD will designate a Distributed Active Archive Center (DAAC), which is responsible for public distribution of ICESat-2 data and long-term science data archiving.

The ICESat-2 Project is aided in the development phase by the ICESat-2 Science Definition Team (SDT), which will be succeeded in the execution phase by an ICESat-2 Science Team (ST). These science teams are composed of competitively selected scientists with expertise spanning the disciplines of laser altimetry; geodesy; glaciology; sea ice science; ecosystem structure science; atmospheric sciences, especially cloud science; and relevant aspects of land, ocean, hydrologic, and applied sciences. Both teams have a competitively selected team leader who represents them to the Project. The SDT and ST tasks are to:

- Determine the requirements necessary to meet the Baseline Science Objectives;
- Provide guidance for the development of calibration and validation plans for the mission;
- Define the geophysical products and data sets to be provided by the mission, and identify algorithm work required to create these products and data sets;
- Identify and perform the necessary prelaunch studies to meet the science objectives, and evaluate such studies when completed;
- Identify the ground system necessary to support the mission scientific goals;
- Consider the scientific impacts of project de-scoped capabilities taken during development;
- Consider the scientific impacts of changes in mission operations that might be identified or occur during the implementation and on-orbit phases of the mission; and
- Provide liaison with the broader science and applications communities.

In October 2008 NASA competitively selected an SDT for a three-year term, with team membership re-competed in 2011. In 2014, the SDT will be succeeded by the ST for the execution phase of the ICESat-2 mission. The ST will be re-competed for successive three-year terms until mission completion.

3.2 Project Acquisition Strategy

Sufficient funding will be set aside from the Project-controlled budget for the LV. ICESat-2 will be designed to enable flight on the smallest possible LV without jeopardizing the L1-Requirements. The laser system will be procured from commercial sources using NASA-GSFC expertise to facilitate contractor designs and ensure contractor performance.

4.0 PROGRAMMATIC REQUIREMENTS

4.1 Science Requirements

A scientifically viable mission advancing the objectives in Section 2.1 can be achieved if ICESat-2 satisfies the baseline or threshold mission requirements listed here respectively. The baseline mission provides substantially more value to NASA and the Earth science community.

4.1.1 Baseline Science Requirements

- a) ICESat-2 shall produce an ice surface elevation product that enables determination of ice-sheet elevation change rates to an accuracy of better than or equal to 0.4 cm/yr on an annual basis.
- b) ICESat-2 shall produce an ice surface elevation product that enables determination of annual surface elevation change rates on outlet glaciers to an accuracy of better than or equal to 0.25 m/yr over areas of 100 km² for year-to-year averages.
- c) ICESat-2 shall produce an ice surface elevation product that enables determination of surface elevation change rates for dynamic ice features that are intersected by its set of repeated ground-tracks to an accuracy of better than or equal to 0.4 m/yr along 1-km track segments.
- d) ICESat-2 shall produce an ice surface elevation product that enables resolution of winter (accumulation) and summer (ablation) ice-sheet elevation change to 10 cm at 25-km x 25-km spatial scales.
- e) ICESat-2 shall provide monthly surface elevation products to enable, when sea surface height references (leads) are available and under clear sky conditions, the determination of sea-ice freeboard to an uncertainty of less than or equal to 3 cm along 25-km segments for the Arctic and Southern Oceans; the track spacing should be less than or equal to 35 km at 70 degrees latitude on a monthly basis.
- f) ICESat-2 shall make measurements that span a minimum of three years.
- g) ICESat-2 shall produce an ice surface elevation product that, in conjunction with ICESat-1, enables determination of elevation changes on a decadal time scale.
- h) ICESat-2 shall produce elevation measurements, that enable independent determination of global vegetation height, with a ground track spacing of less than 2 km over a 2-year period.
- i) The ICESat-2 Project shall conduct a calibration and validation program to verify delivered data meet the requirements in 4.1.1 a, b, c, d, e, g and h.

4.1.2 Threshold Science Requirements

- a) ICESat-2 shall produce an ice surface elevation product that enables determination of ice sheet elevation change rates to an accuracy of better than or equal to 2 cm/yr on an annual basis.
- b) ICESat-2 shall produce an ice surface elevation product that enables determination of annual surface change rates of outlet glaciers to an accuracy of better than 0.50 m/yr over areas of 100 km² for year-to-year averages.
- c) ICESat-2 shall produce an ice surface elevation product that enables determination of surface elevation change rates for dynamic ice features that are intersected by its set of repeated ground-tracks to an accuracy of better than or equal to 0.8 m/yr along 1-km track segments.
- d) ICESat-2 shall produce an ice surface elevation product that enables resolution of winter (accumulation) and summer (ablation) ice-sheet elevation change over slopes less than 1° to 5 cm at 25-km x 25-km spatial scales.
- e) ICESat-2 shall provide monthly surface elevation products to enable, when sea surface height references (leads) are available and under clear sky conditions, the determination of sea-ice freeboard to an uncertainty of less than or equal to 3 cm along 50-km segments for the Arctic and Southern Oceans; the track spacing should be less than or equal to 35 km at 70 degrees latitude on a monthly basis.
- f) ICESat-2 shall make surface elevation measurements over ice sheets and sea ice for no less than a 3-year duration for at least 182 days each year to provide seasonal sampling.
- g) The ICESat-2 Project shall conduct a calibration and validation program to verify delivered data meet the requirements in 4.1.2 a, b, c, d, and e.

4.1.3 Mission Success Criteria

The ICESat-2 Mission will be considered successful if it measures global, space-based elevation data of the polar sea ice and the ice sheets of Antarctica and Greenland with the precision, resolution, and coverage needed to improve understanding of their changes over one annual cycle as follows:

- Measures the elevation of the Greenland and Antarctic ice sheets to within 10 cm over areas with slopes less than 1 degree;
- Measures the height of the Arctic sea ice above the adjacent ocean to within 5 cm;
- Records, calibrates, validates, publishes, and archives science data records and calibrated geophysical data products in a NASA DAAC for use by the scientific community.

4.2 Mission and Spacecraft Performance

- a) ICESat-2 shall be a Category 2 project as defined in the NASA Procedural Requirement (NPR) 7120.5E.
- b) The ICESat-2 payload risk classification shall be Class-C as defined in NPR 8705.4, subject to confirmation with the SMD/Office of Chief Engineer (OCE) and Office of Safety and Mission Assurance (OSMA).
- c) The ICESat-2 mission shall complete the In-Orbit Checkout (IOC) period within 60 days after launch, and then begin operations to satisfy the science requirements in Section 4.1.

4.3 Launch Requirements

- a) LV Category-2 is acceptable in accordance with NPD 8610.7D.
- b) The ICESat-2 mission launch readiness date shall target December 2016.

4.4 Ground System Requirements

The ICESat-2 Project shall develop a ground system to command and operate the spacecraft and instruments, and to generate the data products needed to meet the science requirements in Section 4.1 and data latency requirements in Section 4.5.

4.5 Mission Data Requirements

4.5.1 Science Data Management

- a) The ICESat-2 Project shall produce the standard science data products listed in Table 1.

Table 1. ICESat-2 Data Products

Data Product	Description	Time beyond In-Orbit Checkout (IOC) to deliver initial data	Maximum data latency after first release
Level 0	Raw Instrument Data	3 months	24 hours
Level 1	Engineering Unit (EU)-Converted Data	3 months	72 hours
Level 2a	Geolocated Range and Elevation Data	6 months	72 hours for first release; 2 weeks with full Precision Orbit Determination / Precision Pointing Determination (POD/PPD)
Level 2b	Derived Geophysical Along-track Data	6 months	1 month after completion of data accumulation required for individual geophysical products
Level 3	Derived Gridded Geophysical Data	6 months	1 month after completion of data accumulation required for individual geophysical products

- b) All original observation data and standard science data products listed in Table 1, along with the scientific source code for algorithm software, coefficients, and ancillary data used to generate these products shall be delivered to the designated NASA-SMD/ESD-assigned Data Center. There shall be no period of exclusive access.
- c) Science algorithms used to generate the standard science data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).
- d) The ICESat-2 Project will coordinate with the NASA-SMD/ESD-assigned Data Center regarding the release of product versions to ensure completeness and accuracy of quality information and validation status of the ICESat-2 science data products.
- e) The ICESat-2 Project will coordinate with the NASA-SMD/ESD-assigned Data Center on the data and information to be transferred at ICESat-2 Project closeout.

4.5.1.1 Science Data Requirements

- a) ICESat-2 science data product formats shall conform to the standard selected from the published list of NASA-SMD/ESD-approved Data System Standards.
- b) ICESat-2 science data products metadata shall conform to ISO 19115 Geographic Information-Metadata standards and adhere to the published NASA-SMD/ESD-approved implementation. The latter will be published well within the time needed for ICESat-2 utilization on an Earth Science Data Systems website currently under development.
- c) The ICESat-2 Project shall transfer to the NASA-SMD/ESD-assigned Data Center all the information and documentation required for long-term preservation of knowledge about the products resulting from the project, as defined in the NASA Earth Science Data Content Standard. The latter will be published well within the time needed for ICESat-2 utilization on an Earth Science Data Systems website currently under development.
- d) The ICESat-2 Project shall organize and host an ICESat-2 data product application workshop annually and/or participate in the appropriate NASA-SMD/ESD mission applications meeting(s). The workshop or meeting will share information on ICESat-2 science requirements and data products and define potential applications that can be supported or developed within existing ICESat-2 data requirements. The ICESat-2 Project shall provide results of the workshops and meetings to the ICESat-2 SDT/ST and make available information about potential or actual applications at other ICESat-2 workshops and meetings and to the public.

5.0 MISSION REQUIREMENTS

5.1 Cost Requirements

- a) The total cost for the ICESat-2 mission shall include the formulation, implementation, launch, operations, calibration, validation, and generation of science data products defined in Section 4.
- b) The total cost for the ICESat-2 mission shall include the SDT and ST, whose roles and scope are described in Section 3.1.
- c) Contributions from non-NASA partners shall be without exchange of funds between NASA and those partners.
- d) The total NASA cost (including Civil Servant (CS) labor but excluding HQ-held reserves (i.e., Unallocated Future Expenses (UFE)) and pre-formulation costs) for the ICESat-2 mission shall be \$776.3M.

5.2 Cost Management and Scope Reduction

- a) Provided that Program Level Requirements are preserved and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, ICESat-2 shall pursue scope reduction and risk management as a means to control cost.
- b) Scope reductions from baseline science requirements to threshold science requirements or potential scope reductions affecting these program requirements shall be agreed by the officials represented on the approval page of this document.

6.0 MULTI-MISSION NASA FACILITIES

- a) The ICESat-2 mission shall use the NASA Near-Earth Network (NEN) for S-band uplink and downlink and X-band for downlink.
- b) The ICESat-2 mission shall use the NASA Tracking and Data Relay Satellite System (TDRSS) for critical event telemetry visibility when NEN assets are not otherwise available or sufficient.
- c) The ICESat-2 mission shall use the NASA Earth Observing System Data and Information System (EOSDIS) Data and Operations System (EDOS) for data preprocessing, and the NASA EOSDIS infrastructure, including the NASA-SMD/ESD-assigned Data Center for science data archive and distribution.

7.0 EXTERNAL AGREEMENTS

All agreements between NASA and each non-NASA mission partner shall be coordinated through NASA SMD and the NASA Office of External Relations.

8.0 PUBLIC OUTREACH AND EDUCATION

To comply with the STEM (Science, Technology, Engineering and Mathematics) Education Consolidation in the President's Budget for Fiscal Year 2014, NASA SMD has descoped all remaining Education and Public Outreach (EPO) activities from ICESat-2 beginning in FY14 and removed the associated funding from the project. The project will support future EPO activities as direction and additional funding are provided.

9.0 SPECIAL INDEPENDENT EVALUATION

No special independent evaluation is required for the ICESat-2 Project.

10.0 WAIVERS

Any waivers to NPR 7120.5 requirements or processes shall be processed and approved in accordance with the existing NASA-GSFC and NASA Agency processes for Category A waiver approval.

11.0 REQUIRED APPROVALS AND CONCURRENCES

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